N92-15856

1991

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

EVALUATION OF SCHEDULING TECHNIQUES FOR PAYLOAD ACTIVITY PLANNING

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Contract No.:	NGT-01-008-021 The University of Alabama in Huntsville

Two tasks related to payload activity planning and scheduling were carried out. The first task involved making a comparison of space mission activity scheduling problems with production scheduling problems. The second task consisted of a statistical analysis of the output of runs of the Experiment Scheduling Program (ESP). Details of the work which was performed on these two tasks are presented in the separate sections which follow.

TASK 1

Description. A paper entitled "A Comparison of Space Mission Activity Scheduling Problems with Production Scheduling Problems" was written (reference 1). This paper will be submitted for possible publication as a NASA Reference Publication.

Objectives. It was felt that a need existed for a "bridge" between the literature in space mission activity scheduling and the literature in production scheduling. Writing a document which compared the two problems was seen as the best means of providing this bridge. This document could then serve to introduce the two problems to those not familiar with one, or both, of them. For example, those who are familiar with space mission activity scheduling problems (generally NASA personnel and NASA contractor personnel) might use the document to gain a better understanding of the literature on production scheduling problems, and how it relates to space mission activity scheduling. Similarly, those who are familiar with production scheduling problems, including academic and industrial researchers, as well as newly-graduated engineers, could use such a document as an introduction to space mission activity scheduling problems.

Another objective of this task was to identify possible areas for further research in space scheduling problems. This was done by examining the literature for both types of scheduling problems to see which approaches had been successful, and by considering the effects of the important differences in the two types of problems.

Approach. The document produced in Task 1 begins with a brief discussion of scheduling problems in general. This is followed by a comparative description of space mission activity scheduling problems and production scheduling problems. For each of the problem types, the associated terminology is reviewed. This is followed, for each case, by a detailed problem description which covers the problem environment, typical objectives, and typical constraints. A discussion of the solution approaches which have been applied to each problem type is included. Finally, some areas for further research in space scheduling problems are identified.

Results. The comparison of the two scheduling problems pointed out the similarities between them, especially in terms of their level of difficulty and the solution approaches which have been applied to them. However, several important differences in the problems were identified. Some of these differences are discussed below.

In production scheduling problems, machine capacity is often assumed to be the only constraining resource. In a very few studies, other resources such as labor or tooling are considered. In space mission scheduling, on the other hand, many different types of resources act as important constraints on the system, and must be considered when solving the scheduling problem. This consideration of multiple resource types makes the space mission activity scheduling problem an extremely difficult one.

The objectives of the two scheduling problems are quite different. In production problems, the objectives of interest generally include those related to job completion times (e.g., flowtime and makespan), those related to due dates (e.g., mean or maximum tardiness or lateness, number of tardy jobs, etc.), and/or those related to inventory and utilization costs (e.g., average number of jobs waiting, machine utilization percentages, etc.). In space mission activity scheduling, the single major objective is the maximization of the scientific return from the mission. Because of the difficulty of measuring this objective directly, surrogate measures such as the number of activity model performances scheduled, the amount of crew time scheduled, the amount of experiment time scheduled, or a subjectively weighted schedule grade, are generally used.

There are a number of important differences in the constraints on the two types of scheduling problems. In general, space mission activity scheduling problems tend to have many more constraints than production scheduling problems. One major difference in the two problem types is that space missions have a finite duration. Because of this, only a subset of the activities which could be scheduled actually will be scheduled. In production problems, on the other hand, all jobs are generally scheduled eventually. Those which cannot be completed in one week will be completed in the following week, for example.

In space scheduling problems, another important type of constraint is the existence of time windows in which the activities must be scheduled. These constraints arise because of the position or attitude of the spacecraft or target objects, the nature of the scientific experiment or activity being performed, the duty cycles of the crew members, etc. In most production scheduling problems, the analogous types of constraints are either unimportant or are ignored for convenience.

Some of the other complicating constraint types in the space mission activity scheduling problem include the existence of complex resource availability profiles for the multiple resource types, the possibility of concurrent activities, the existence of variable step durations, the requirement that there be a certain minimum time delay between adjacent steps in an activity model or between different performances of the same model, the requirement that certain resources remain unavailable for use during such time delays, the requirement that certain steps in an activity be performed by the same crew member(s), and the possible existence of alternate scenarios for an activity. Some of these constraints have analogies in the production scheduling environment, but these are usually not considered in such problems.

The document produced in Task 1 provides a review of the solution approaches which have been applied to each of the types of scheduling problems. Much of the general scheduling literature deals with theoretical issues and very small scheduling problems (e.g., single-machine scheduling). Optimization approaches have been applied in both problem environments, but have been of limited practical use because of their computational burden. Because of this, heuristic approaches have generally been used to solve realistic problems of both types. Various heuristic approaches are reviewed in the paper, with special emphasis on ESP (see reference 2) and other robust payload activity scheduling programs. Finally, artificial intelligence approaches to scheduling are discussed.

The last result of the Task 1 document is the identification of areas where further research is needed. In the short term, the most promising area appears to be the investigation of methods for improving heuristic approaches such as ESP. Three specific areas of possible improvement were identified. First, the decomposition of the scheduling problem by defining "artificial" time windows for activities should be examined. In ESP, such a decomposition can be easily accomplished by using the macro windows feature of the program. Currently, macro windows are used merely to define the mission duration. However, they could be used to help control the placement of activities onto the mission timeline, and to artificially break a large scheduling problem into several smaller problems in order to reduce the time required to obtain a solution. Research is needed to determine effective methods for defining the macro windows, and to determine the effects of their use on solution time and the quality of the schedule obtained.

In ESP, activities are placed onto the mission timeline one at a time. The order in which activities are selected for placement has a significant impact on the final schedule. Several selection methods are currently available, but more robust methods are needed. Finally, the use of rescheduling in heuristics such as ESP should be examined. In some heuristics, including ESP, an activity which has been placed on the timeline will not be rescheduled. Other heuristics do reschedule activities. Rescheduling promises improved schedules, but this improvement is at the expense of increased computational requirements. An analysis of the relative costs and benefits of rescheduling, as well as the definition of appropriate rescheduling methods, needs to be performed.

The relatively new field of artificial intelligence holds promise for scheduling applications, particularly in the long term. Further research in this area is needed.

TASK 2

Description. A statistical analysis of the output from ESP runs for two space station data cases was performed. Using the random activity selection rule, 60 runs were made for a relatively difficult data case, and 95 runs were made for a relatively easy data case.

Objectives. It was hoped that Task 2 would provide knowledge on the number of ESP runs required to reach a specified level of confidence in the results. A closely related objective was to suggest how analysts could, after obtaining the results from several runs, make their own determination as to the need for making additional runs.

Approach. For the difficult data case, the 60 runs were randomly divided into groups of size 1, 2, 3, 5, and 10. The best run of each group for each of four performance measures (schedule grade, number of performances scheduled, crew time scheduled, and experiment time scheduled) was then identified. Within each group size/performance measure combination, statistical analyses were performed on the best runs of each group to find the mean value, minimum and maximum value, upper and lower tolerance limits (see reference 3), and a crude estimate (mean value plus three standard deviations) of the optimal value. The same approach was used for the easier data case, with the 95 runs being randomly divided into groups of size 1, 3, 5, and 10.

Results. As expected, the data for the two cases indicates that the number of runs needed to reach a given confidence level is highly dependent upon the amount of variation within the data. After making several runs (e.g., five), it is recommended that the mission planner carry out an analysis like the one performed here. The closeness of the best solution obtained to the upper tolerance limit and estimated optimal value should then indicate whether additional runs should be made.

REFERENCES

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